Endoparasitic helminths of the European eel, *Anguilla anguilla*, from four disconnected meanders from the rivers Leie and Scheldt in western Flanders, Belgium

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Abstract. The endoparasitic helminth communities of the European eel, *Anguilla anguilla* (L.), were investigated in four meanders, cut off from the rivers Leie and Scheldt in western Flanders, Belgium. Six species of helminths (2 cestodes, 2 nematodes and 2 acanthocephalans) were found. The dominant parasite species was the nematode *Anguillicola crassus* (Kuwahara, Niimi et Itagaki, 1974) infecting 79% of the eel population with intensities up to 1 12 specimens per fish. At two localities no acanthocephalans could be found, whereas these parasites were very common at the other sites. The prevalence, mean intensity, intensity and abundance, their correlation to the body length, and the frequency distributions were analysed. The site selection of parasites is in relation to food composition and feeding habits of eels, physiological and structural differences in the intestine and possible interspecific competition were discussed.

The European eel, *Anguilla anguilla* (L.), is one of the most economically valuable freshwater fish in Belgium. During the last 20 years the poll ution of big rivers and the limited migration possibilities for the mature silver eels caused a serious decline in glass ee] catches at the Belgium coast (Denayer and Belpaire 1993).

Since the introduction of *Anguillicola crassus* (Kuwahara, Niimi et Itagaki, 1974) at the end of the 1980s, many papers have been published dealing with the prevalence, life-cycle, distribution, paratenic hosts and pathogenity of this nematode (Taraschewski et al. 1987, Belpaire et al. 1989, De Charleroy et al. 1990, Molnár et al. 1991, 1994, Höglund and Thomas 1992, Thomas and Ollevier 1992, Moravee and Konecny 1994).

In spite of the relatively well studied anguillicolosis, only a few extensive hel mi nthological studies deali ng with the intestinal parasites of the European eel have been carried out (Kennedy 1985, Moravec 1985, Kennedy and Moriarty 1987, K0ie 1988, Nie and Kennedy 1991a,b, 1992, Kennedy et al. 1992).

MATERIALS AND METHODS

Between 29 April and 6 May 1994, 107 eels (size range 24-90 cm) were sampled in the ri ver Leie and Scheldt. For details on sampling sites and fishing methods see Schabuss et al. (1996). All eels were kept in aquariums without feeding and were immediately dissected after killing. The total length (± 0.1 cm) and weight (± 0.1 g) of each eel were recorded along with the number and location of the parasites in the gut (A = anterior, B = middle, C = posterior part). The swimmbladder, the intestine tract of every eel and the eyes of 10% of the fish were examined with the conventional parasitological techniques (Moravec et al. 1992).

All parasites were fixed in 4% formaline. Same big specimens of acanthocephalans and cestodes were slightly pressed between two glass slides before the fixation.

Acanthocephalans and cestodes were transferred into water for 3 days, stained in borax carmine for 2 weeks and subsequently destined in 1% hydrochloride acid alcohol. After differentiation the specimens were dehydrated in a series of alcohol (70, 80. 96, 1 00%), cleared in Gaulteria oil and mounted in Araldit resin.

In order to avoid any misunderstandings with the terms prevalence, intensity, mean intensity and abundance the definitions of Margolis et al. (1982) were used. The Simpson (D = 1/((Pi)2) index and the Shannon diversity index (H = -L: (Pi log2 Pi) were calculated (Begon et al. 1986, Kennedy 1995). For the statistica! analysis of the terms mentioned above the Kruskal-Wallis test was used and in case of significant differences, the Mann Whitney-Wilcoxon Rank Sum W test was applied in order to detect the distinct variances between localities.

Table 1. Prevalence (P %), intensity (Int.), mean intensity (M.i.) and abundance (Abund) of the parasite species; n = number of eels examined

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Within the investigation of 107 eels, six endoparasi-

Proteocephalus macrocephalus (Creplin, 1825)
Bothriocephalus claviceps (Goeze, 1782)

Nematoda

Anguillicola crassus (Kuwahara, Niimi et ltagaki, 1974)
Camallanus lacustris (Zoega, 1776)

Acanthocephalus lucii (Müller, 1776)
Acanthocephalus anguillae (Müller, 1780)

Only 2 specimens of *Bothriocephalus claviceps* and one of *Camallanus lacustris* were found and, therefore, these parasites were not included in the further analyses. The dominant parasite species of the investigated eels was *Anguillicola crassus* with the prevalence of 79% (Table 1, Fig. 1) and the abundance of 9 individuals per

with 19.6 parasites per infected 'host (Fig. 2) and the highest intensity with 170 specimens in one eel (Table 1) was recorded for *Acanthocephalus lucii*.

At Kerkhove and Ooigem nó acanthocephalans were

Baafs-vijve and especially at Bavikhove, where *A. lucii* and *A. anguillae* infected 71 and 68% of the examined

The mean number of *lucii* per infected host at Ba-
hosts respectively (Table 1, Fig. 4).

value of 4 (Fig. 5). At St. Baafs-vijve the mean intensity

of *A. anguillae* per host was recorded (Fig. 5).

Concerning the abundance, *A. lucii* was the dominant

about ten times more abundant than *A. lucii* at St. Baafs-vijve (Fig. 6).

The statistica! analysis indicated significant differences concerning the infection with acanthocephalans

lucii and *A. anguillae* differed between Bavikhove and

of *A. lucii* at Bavikhove showed a distinct difference ($p < 0.001$) to all othèr sampling sites. *A. anguillae* did not differ in its prevalence or abundance between Bavikhove and St. Baafs-vijve, but indicatecl significant differences ($p < 0.001$) to Ooigem and Kerkhove.

Proteocephalus macrocephalus was found at all four investigated meanders with high prevalences at the Jocalities Bavikhove (65%) and Kerkhove (63%; see Fig. 4). The mean intensity of this cestode showed no distinct variance between the four Jocalities. St. Baafsabundance differed significantly to the other localities ($p < 0.01$).

The prevalence and mean intensity were compared with the body size in order to find any differences of the parasite infection between the size classes (Figs. 7-8). *P. macrocephalus* showed a significantly increase ($p < 0.001$) of the prevalence from 28% at the size class smaller 40 cm to a maximum value of 91% at the largest size class (Fig. 7). Corresponding to the enlarging prevalence the mean intensity of the eels larger than 60 cm was also significantly different compared to the other size classes ($p < 0.01$). The other parasite species showed no significant relation to the length of the eels.

The swimmbladder nematode *Anguillicola crassus* was present at all four localities (Fig. 4). The infection of 65% at Bavikhove was significantly different ($p < 0.001$) to the maximum prevalence at Ooigem (90%). The mean intensity of this nematode varied from 5 at Bavikhove (significantly different to the other meanders) up *to* 19 specimens at St. Baafs-vijve (Fig. 5). The maximum intensity of 112 specimens per fish was recorded at St. Baafs-vijve (Table 1). The low abundance of 3 specimens at Bavikhove was significantly different ($p < 0.05$) to the other localities.

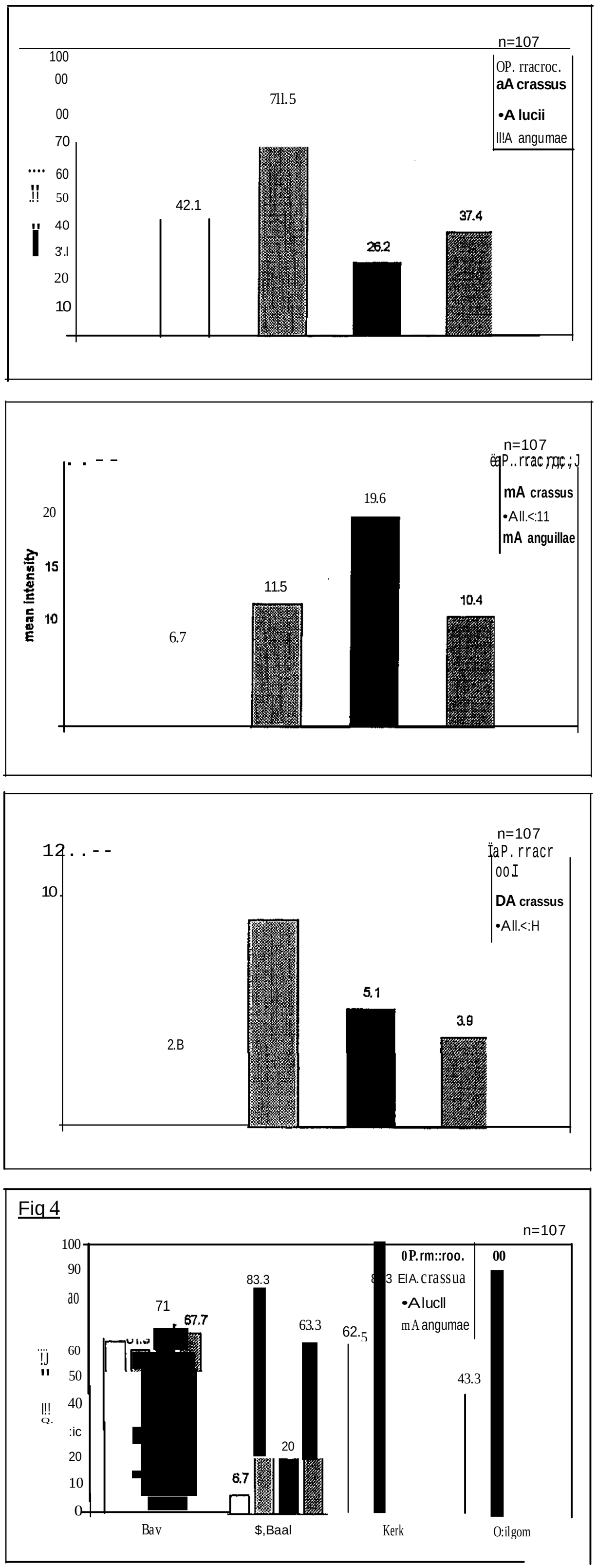
The frequency distribution of the parasites within the host population indicated an overdispersed system. Most eels were either not or just slightly infected and only a few individuals were harbouring many parasites, with intensities up to 170 specimen per fish (Figs. 9-12).

The analysis of the Simpson and Shannon indices indicated that the meander of Bavikhove was significantly different ($p < 0.001$, Tables 2-4) to the ether investigated localities.

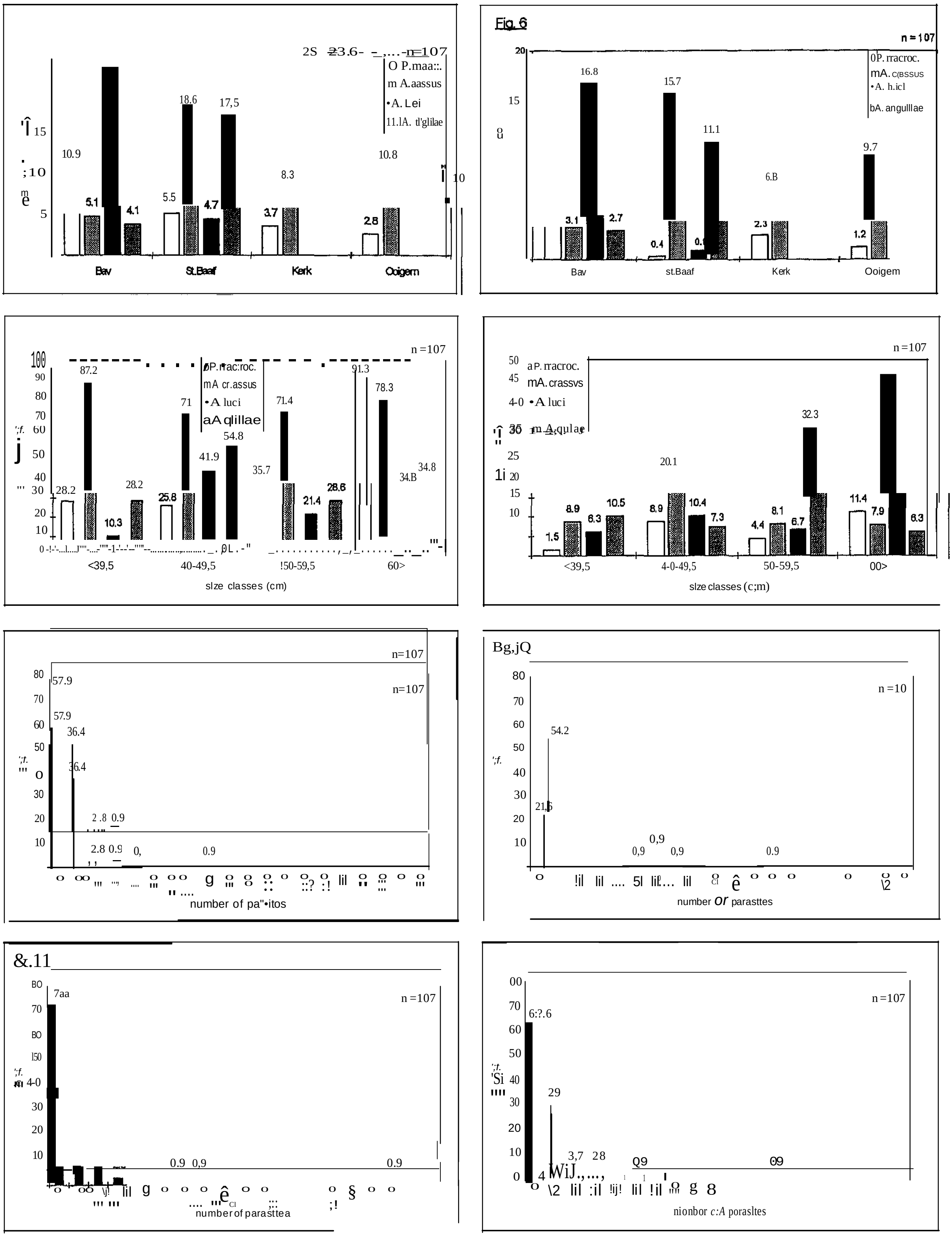
In order to investigate the microhabitat selection of the parasites, the intestine was divided into 3 sections and their infection rates were recorded. The differences between the sections were significant (Figs. 13-16). The acanthocephalans, especially *A. anguillae* (80%), were dominant in section B. Forty four percent of the *A. lucii* were Iocated in section C; *A. anguillae*, however, were found only in small numbers in this posterior part of the intestine.

The prevalence of *A. lucii* and *A. anguillae* in section B was significantly higher than in the other intestine sections ($p < 0.001$). The mean intensity (Fig. 16) did not differ significantly between the three sections.

Proteocephalus macrocephalus was present with 64% of its population in the anterior part of the gut, but few specimens could be found in section C (Fig. 13). The prevalence of *P. macrocephalus* (Fig. 15) in section A was significantly different ($p < 0.001$) to the other parts of the gut.



Figs. 1-4. Overall prevalence (Fig. 1), mean intensity (Fig. 2) and abundance (Fig. 3) of eel parasites from the investigated localities. Prevalence of eel parasites at different investigated Iocalities (Fig. 4).



Figs. 5-12. Mean intensity (Fig. 5) and abundance (Fig. 6) of eel parasites at different investigated localities. Prevalence (Fig. 7) and mean intensity (Fig. 8) correlated with the body size. Frequency distribution of *Proteocephalus macrocephalus* in the intestine of *Anguilla anguilla* (Fig. 9), *Anguillicola crassus* in the swimmbladder (Fig. 10), and *Acanthocephalus lucii* (Fig. 11) and A. *anguillae* (Fig. 12) in the intestine of A. *anguilla*.

DISCUSSION

The composition and structure of the eel parasite communities investigated in this study appear to be very typical of and similar to, eel parasite cornmunities described by ether authors (Moravec 1985, Kennedy et al. 1992). These communities are in genera!, species poor showing low diversity and high dominance by a single species (Esch et al. 1988, Kennedy 1990). Virtually all are composed of a mixture of eel specialists (in this case *Anguillicola crassus, Proteocephalus macrocephalus* and *Bothriocephalus claviceps)* and generalists *(Acanthocephalus lucii, A. anguilla,* and *Camallanus lacustris).*

Corresponding to the publication of Kennedy et al. (1992), the great majority of indi vidual parasites *(A. crassus, P. macrocephalus)* in the investigated localities were transmitted to eels by plankton, but the importance to the composition and structure of eel parasite communities of these species was overlooked or at least underemphasized previously.

In contrast to other authors (Kazié et al. 1982, K0ie 1988, Nie and Kennedy 1991a), the prevalence of *P. macrocephalus* was relatively high with the maximum value of 64.5% at Bavikhove. This cestode showed a significant relationship to the length of the eels, with the maximum prevalence and mean intensity at the largest size class. This fact seems to reflect the correlation between the increasing infection rate and the increasing

Table 2. Diversity indices of the different localities.

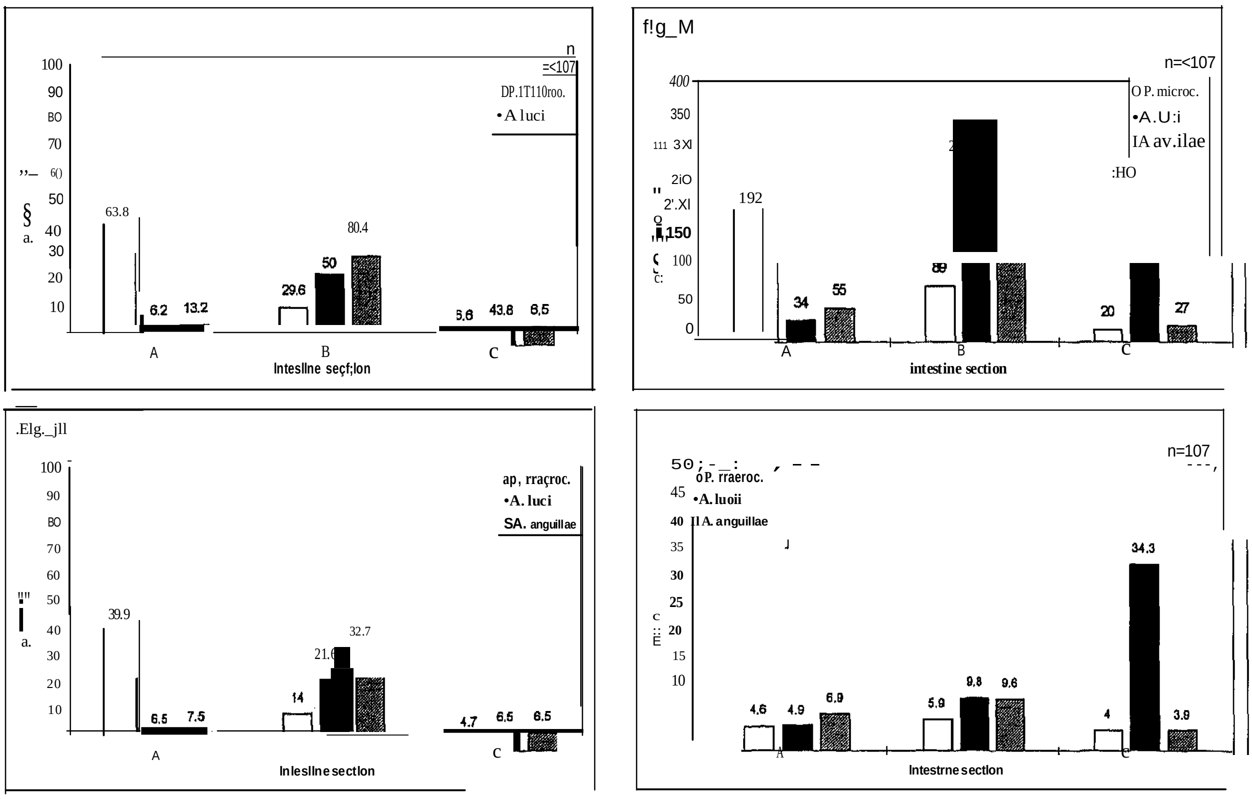
	Shannon index	Simpson index
Ooigem	0.3293	0.75287
Kerkhove	0.4231	0.74372
Bavikhove	1.0272	0.56861
St. Baafs-vijve	0.4385	0.80634

Table 3. Mann-Whitney and Wilcoxon Rank Sum W test to compare the Shannon diversity index of the different parasite cornrnunities (+++ - $p < 0.001$)

	Ooigem	Kerkhove	Bavikhove
Ooigem			
Kerkhove			
Bavikhove	+++	+++	
St. Baafs-vijve			+++

Table 4. Mann-Whitney and Wilcoxon Rank Sum W test to cornpare the Simpson diversity index of the different parasite communities (+++ - $p < 0.001$).

	Ooigem	Kerkhove	Bavikhove
Ooigem			
Kerkhove			
Bavikhove	+++	+++	
St. Baafs-vijve			+++



Figs. 13-16. Proportion (Fig. 13) and number (Fig. 14) of parasites for each intestine section. Prevalence (Fig. 15) and meao intensity (Fig. 16) of the different intestine sections.

feeding of larger eels on copepods with infective larval parasite stages (Moravec and Scholz 1991). The high prevalence of *P. macrocephalus* could also be caused by a high transmission rate of its intermediate hosts and there may be also a çorrelation to the life-cycle of this cestode (Scholz and Kepr 1988).

Surprisingly the infection of the dominant parasite species, *A. crassus*, where copepods serve as an intermediate host too, was not significantly higher in larger fish. Lower transmission rates of *A. crassus* by paratenic hosts and increased immunological responses of larger eels probably explain this difference in infection levels (Haenen et al. 1993, Nagasawa et al. 1994).

The generalist parasite species *A. lucii* and *A. anguillae*, transmitted by benthic invertebrates, were completely absent at two localities. This situation was probably caused by the low amount of suitable intermediate hosts like the aquatic isopod *Asellus aquaticus*, but more detailed investigations concerning the presence or absence of possible intermediate hosts for acanthocephalans are required to prove this hypothesis.

The frequency distribution of the specialists and generalists showed overdispersion with few heavily infected eels. These individuals serve as a reservoir for the whole parasite population (Pennycuick 1971). The big differences of infection reflect the heterogeneity of the host population like different feeding habits and preference of specific food items of the individual eel, different expositions to parasites and infective stages, and differences in the immune systems (Anderson 1978, 1993, Esch et al. 1988).

Significant differences concerning the site segregation of *P. macrocephalus* (dominant in the anterior part) and the acanthocephalans (dominant in the middle part) were recorded. This situation is often explained by the special structure of the anterior intestine wall, so that the cestodes can easily attach to the gut (Whitfield 1979), different physiological conditions in the intestine or interspecific competition (Dogiel 1962, Kennedy 1985, Kennedy and Moriarty 1987). Different feeding strategies of the parasites or chance assemblages with vacant niches could also be the reason for this situation, but more investigations have to be made to explain this phenomenon completely.

Comparing the parasite community structures of the four sampling sites, Bavikhove was the only locality where the generalistic acanthocephalans represented the dominant parasite species. The Simpson and Shannon indices and the significantly different values of the prevalence, mean intensity and abundance indicated the special parasite community at Bavikhove, too. The composition and abundance of suitable intermediate and definitive hosts may contribute to this situation.

The evidence from this study of helminth communities in eels is thus very clear. The parasite species transmitted by plankton often dominate eel parasite communities. The significant relation of *P. macrocephalus* with the size of the eels indicate that eels are associated in their habits with plankton and eels of all sizes feed regularly on copepods in all localities. Infections of acanthocephalans provide evidence that the eels also feed intensively upon benthic invertebrates. This study shows that if the life-cycles of the parasites and modes of transmission to fish are known, parasites can be used as biologica! tags to provide information on host movements, habits and feeding behaviour.

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